

Update on Material Compatibility Testing for Decontamination Methods Used for *Bacillus anthracis* (Anthrax)

Purpose

This technical brief provides decision makers with a practical summary of the latest U.S. EPA information on the material compatibility of decontamination techniques that have been found to be effective in inactivating *Bacillus anthracis* spores on different materials.

Summary

This technical brief provides an overview of data and information on the material compatibility of decontamination technologies used to inactivate spores of *B. anthracis*, that were not included in previous technical briefs (i.e., U.S. EPA, 2014; U.S. EPA, 2017A) on this topic. These previous technical briefs summarized studies that were primarily focused on fumigant-based decontamination approaches (chlorine dioxide gas, hydrogen peroxide vapor, methyl bromide, and ethylene oxide). This current tech brief provides a summary of new information and data on the material impacts of gaseous-based decontaminants as well as techniques utilizing liquid or physical-based decontamination approaches. The decontamination techniques discussed in this tech brief have been found to be effective in the laboratory and in the field under certain test conditions (Wood and Adrion, 2019), and thus have been assessed for deleterious impacts on materials under similar conditions.

Introduction

In the event of a *B. anthracis* spore release, there are several decontamination techniques available that have been proven effective in inactivating *B. anthracis* spores on many types of materials. In addition to decontamination efficacy, there are other criteria that may be used as the basis for the selection of a decontamination method, such as its cost, health and safety implications, and compatibility with materials. Some decontamination technologies may cause corrosion, loss of functionality, and/or visible damage to materials and equipment. These issues may be inconsequential if the material is to be managed as waste. However, certain items, such as those which contain sensitive electronics or are valued for other reasons (e.g., mission criticality, personal or societal significance, rarity, and cost) may need to be decontaminated for

reuse. Some of these critical items, materials, or equipment will be devalued or rendered unusable if they are chemically or physically incompatible with the decontaminants (National Response Team, 2021).

The decontamination technologies (for *B. anthracis* contamination) that have been assessed for compatibility of materials and reviewed in this technical brief are as follows:

- Gamma irradiation
- Methyl bromide (without chloropicrin)
- Methyl iodide
- Low concentration hydrogen peroxide vapor
- Peracetic acid fog
- pH-adjusted bleach (PAB) and diluted bleach

Gamma Irradiation

This decontamination technology was assessed for compatibility with historical materials (U.S. EPA, 2017B) that served as surrogates for irreplaceable cultural objects found in museums, galleries, and archives. Specifically, priority materials included in the study were historical oil paintings and paint test strips; and archival documents, books, and photographs (to represent museum-quality items that would not be easily moved for off-site decontamination). Materials of lesser priority included in the study were historical pastel paintings, wood furniture, porcelain (bread plates produced in early 20th century), fabrics, metal alloy objects (a brass serving tray), and leather (a book cover from 1865).

Coupons of 5 cm X 5 cm cut from the test materials were exposed to either a 30 or 50 kilogray (kGy) dose of gamma irradiation at an off-site facility. The materials were evaluated for impacts via visual inspection (e.g., changes in color, cracking, legibility, etc.) and spectrophotometric techniques. The assessments of materials were conducted prior to the gamma irradiation and again approximately 3 weeks and 5 months afterward.

In general, all materials showed some impact from gamma irradiation at both the 30 and 50 kGy doses, either visually or via the spectrophotometric assessments, but to a lesser extent at the lower dose. More specifically, the degree of the impact varied by the material; at 50 kGy, the porcelain material was visually impacted the most (see Figure 1), while the wood and fabric demonstrated minor impacts, and the metal alloy showed no visual impact. At 30 kGy, the long-term wood, fabric, and metal samples had no visual changes. Impacts to the materials in most cases increased between the short- and long-term assessments. For the priority materials, all long-term 50 kGy samples showed some visual impacts, but the impacts were generally minor.

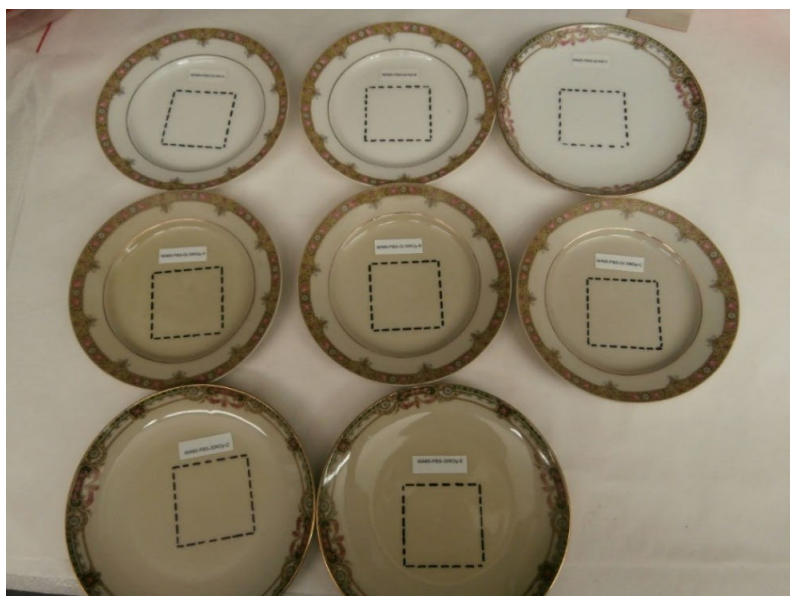


Figure 1. Visual impacts to porcelain plates exposed to gamma irradiation.

Methyl Bromide (with no chloropicrin)

In a previous study, the U.S. EPA evaluated the compatibility of fumigating with a mixture of 98% methyl bromide (MB) and 2% chloropicrin (the latter added as an odorant warning agent) on electronic equipment and coupons of various types of materials. From that study, it was found that damage in the form of corrosion occurred for a few materials, as well as damage to computer functionality, such as with the power supplies (U.S. EPA, 2012). Analysis of the corroded surfaces implicated chloropicrin as the primary cause in most of the observed damage.

A follow-on study evaluated the material compatibility of MB without chloropicrin, under conditions that were sporadic in the lab and recently tested in the field (Adrian et al., 2019). In the compatibility study, desktop computers were used as surrogates for high-value electronic equipment and the impact of sporadic fumigation on computer functionality was assessed using visual inspection and diagnostic software. Coupons of various metals that are used in electronics were also exposed to the fumigant. Target fumigation conditions for MB were 200–250 mg/L for 48 h at 24–30 °C and 75–85% relative humidity.

After five months of post-fumigation operation, five out of six methyl-bromide-exposed DVD ± RW optical drives failed. Deterioration of rubber spacers critical to maintaining correct disc geometry was determined to be the root cause. Metal coupons showed no significant differences in weight between control and test samples, indicative of no corrosion. In summary, MB can cause damage to electronic equipment, but damage seems to be limited to organic materials rather than corrosion of metal surfaces.

In a separate field study to investigate the use of MB to decontaminate a U.S. Coast Guard vessel (U.S. EPA, 2021), the marine grade radio, marine grade global positioning system (GPS), and a laptop computer (see Figure 2) were operationally tested following exposure to the MB treatment. No adverse effects were observed for the equipment after fumigating with MB for 48 hours at a concentration of 212 milligrams of MB per liter of air at 70 °F (21 °C) and relative humidity (RH) > 75%. A check of the vessel's electrical system was also performed following fumigation and no adverse impacts were noted.



Figure 2. GPS unit and laptop computer installed in Coast Guard vessel.

Methyl Iodide

The effects of methyl iodide (MI) under conditions reported to be sporicidal in the lab were also evaluated in the study discussed above (Adrion et al., 2019). As with the MB, target fumigation conditions for MI were 200–250 mg/L for 48 h at 75–86 °F (24–30 °C) and 75–85% RH. Methyl iodide fumigation damaged the light-emitting diodes and optical films in computer displays that were powered-on during fumigation, and all six DVD \pm RW optical drives failed. RH sensors exhibited a substantial and sometimes irreversible reduction in sensitivity during and after the MI fumigation. As with the MB, metal coupons showed no indication of corrosion, and damage to electronic equipment appeared to be limited to the organic materials.

Low concentration hydrogen peroxide vapor

The generation of low concentrations of hydrogen peroxide vapor (LCHPV) by vaporizing off-the-shelf aqueous hydrogen peroxide solutions in off-the-shelf humidifiers has been demonstrated to be an effective decontamination technique for *B. anthracis* contamination (Mickelsen et al., 2019; Wood et al., 2016). Due to the high efficacy as well as being relatively simple to use, fumigation via LCHPV was assessed for compatibility with various materials, including metals, small equipment, and computers (see Figure 3; U.S. EPA, 2020). Deleterious impacts on materials and equipment were assessed monthly over a 1-year period following exposure to LCHPV generated using either 3% aqueous hydrogen peroxide, or 8% aqueous hydrogen peroxide. Impacts to materials and equipment that were exposed to the LCHPV were compared to controls (not exposed). Plastic and metal coupons of different types were visually

assessed. Visual assessments and simple functionality tests were performed for small electrical items; and for computers and peripheral equipment, 93 diagnostic tests were performed for each computer monthly.



Figure 3. Placement of test materials and humidifier inside chamber for LCHPV test.

For the LCHPV generated from the 3% aqueous hydrogen peroxide solution, there were minimal compatibility issues observed with the exposed materials and equipment. Visual appearance changes were limited to the low-carbon steel, which showed some minor oxidation. The exposure did not affect the functionality of any equipment, except for a few issues with computers: only four unique subsystem diagnostic test failures occurred (out of over 3,300 diagnostic tests performed; three computers X 93 tests X 12 months), which were not observed in the control computer set, and all were related to the DVD +- RW drive.

For the LCHPV generated using the 8% HP solution, there were minimal compatibility issues as well. As with the LCHPV exposure generated with 3% hydrogen peroxide solution, appearance changes in material and equipment were limited to the low-carbon steel which, as before, showed rust on exposed surfaces. The exposure did not affect the functionality of the small electrical equipment. Three unique subsystem test failures occurred (out of over 3,300 diagnostic tests performed) which were not observed with the control computers; these included minor issues with the sound card, the DVD +- RW drive, and universal serial bus.

In a separate study to investigate the use of LCHPV to decontaminate a U.S. Coast Guard vessel (U.S. EPA, 2021), the marine grade radio, marine grade GPS, and a laptop computer were operationally tested following exposure to the LCHPV treatment. No adverse effects were

observed for these components after exposure to the LCHPV for 96 hours. A check of the vessel's electrical system was also performed following fumigation and no adverse impacts were noted. The LCHPV was generated inside the vessel using several humidifiers filled with aqueous solutions of 3% hydrogen peroxide solution.

Peracetic acid fog

Peracetic acid (PAA) fog is also an effective and simple to use decontamination technique for *B. anthracis* spore contamination, and so it was assessed for material compatibility in the same study described above to assess impacts to materials (U.S. EPA, 2020). In the study, a 4.5% PAA solution was disseminated using an off-the-shelf fogger using 21 mL/m³ volume at lab ambient temperature of ~ 70 °F (21 °C).

The fogging of PAA solution caused appearance changes (e.g., discoloration, oxidation, residue) to a few of the metals (i.e., only to the copper, low-carbon steel, 304 stainless steel, and aluminum metal coupons). Some minor corrosion and/or the formation of a white powdery residue was observed on the electrical switch box, incandescent light, and the smoke detector battery terminals. For the computers, the external, non-metal surfaces had a moderate amount of the same white residue. Internal and external metal surfaces of the computers showed small amounts of rusting and a significant amount of the white residue. Some functionality incompatibilities with the PAA fog were limited to issues with the power button on the mobile phone and the smoke detector giving a false "low battery" alert. For the diagnostic testing of the computers, there was relatively minimal impact: only six subsystem test failures occurred (out of over 3,300 diagnostic tests performed over the year) that were not observed in the control set of computers; four were related to the DVD +/- RW drive and two of the failures were related to the read-only memory drive.

In a separate study to investigate the use of PAA fog to decontaminate a U.S. Coast Guard vessel (U.S. EPA, 2021), the marine grade radio, marine grade GPS, and a laptop computer were operationally tested following exposure to the PAA fog treatment. No adverse effects were observed for these components. A check of the vessel's electrical system was also performed following the PAA fogging and no adverse impacts were noted. Although there was a light salt residue on the vessel surfaces following fogging with PAA, this did not impact the vessel or any of the components that were included in testing. The salt was easily removed by wiping with a wet rag or spraying with water.

pH-adjusted bleach (PAB) spray or fogging with diluted bleach

Although no EPA laboratory studies have been conducted to specifically examine compatibility of materials when using PAB or diluted bleach at conditions applicable for efficacious inactivation of *B. anthracis* spores, the lab and field studies described below incorporated some limited material compatibility evaluations as part of their broader efforts. As the name implies,

PAB is formulated using water as a diluent and adding either vinegar or acetic acid to lower the pH to around 6.5 – 7, and with a target free available chlorine concentration (FAC) between 6,000 – 8,000 parts per million (ppm). Diluted bleach is diluted with water only with a typical target FAC concentration of around 20,000 ppm, although the concentration may vary depending on the study.

In one laboratory study (U.S. EPA, 2015), the impacts of spraying PAB (target FAC concentration of 6,000 – 6,700 ppm; target pH of 6.5 – 7.0) on wallboard were evaluated since wallboard is one of the most common and abundant indoor materials. Coupons consisting of unpainted wallboard and wallboard coated with a matte latex or semi-gloss paint were sprayed with either PAB or deionized (DI) water, with repeat sprays as needed to maintain visible wetness for one hour. Physical assessments (hardness, moisture, surface roughness) were performed on the wallboard coupons 34 days after the spray application of the PAB or DI water. In general, the spray application of PAB showed no evidence of causing lasting effects to the physical integrity of wallboard, regardless of paint finish.

In the event of a wide-area *B. anthracis* contamination incident, the ability to use large-scale commercially available equipment to apply liquid decontaminants such as PAB provides advantages in terms of reduced implementation time, less labor, and potentially lower overall cost. However, a potential drawback is that the spray equipment may not be compatible with many of the sporicidal liquids considered for field-scale *B. anthracis* remediation efforts. Many of these chemicals such as PAB are corrosive and can cause premature material degradation and equipment failure. In one study (U.S. EPA, 2017C), small proxy equipment was used to spray PAB to assess potential impacts on full-scale spray equipment. Two sets of the proxy equipment failed after spraying PAB for four hours; one of the failures was due to a ruptured diaphragm pump seal, while the other was due to corrosion of the brass nozzles, leading to an increase in orifice size (Figure 4). The third set of proxy equipment performed the longest, with failures in some of the plastic nozzles occurring between 15-67 hours of spray time.



Figure 4. Sprayer nozzle failure, showing various stages of corrosion. Nozzle on left is control.

In a large field-scale study, two *B. anthracis* decontamination methods were demonstrated in a mock subway system (U.S. EPA, 2017D). In the first test round, 400 gallons of diluted bleach (at a concentration of 20,000 ppm FAC) were disseminated into the mock subway tunnel using four large foggers. While the fogging decontamination method was generally efficacious in inactivating the bacterial spores, the foggers sustained damage due to the diluted bleach. Visible effects to the foggers included a build-up of white residue on the fogger fans and

atomizers, damage to 3 of the 4 batteries and associated electrical converters, and some patches of oxidation on the steel plumbing fittings. This damage most likely could have been prevented or at least mitigated had the foggers been removed from the decontaminated area as soon as practical, purged and rinsed. (As it was, the foggers were left in the mock subway tunnel for six days prior to their removal and rinsing, to allow for unimpeded sampling.) Damage to the mock subway system components due to the diluted bleach fog was minimal but included occasional small patches of oxidation on some of the metal-based items. However, many of the electrical panels and outlets in the mock subway station were covered in plastic or tape before fogging operations began. Non-metallic surfaces in the mock system, such as concrete, wood, ballast, wallboard, and plastic were unaffected by the bleach fog based on visual inspection.

In the second round of the field demonstration, nearly 600 gallons of PAB were sprayed onto the surfaces of the mock subway system. A low-pressure chemical sprayer equipped with four hoses and spray wands was used to spray the PAB, at a target rate of 16 gallons per 1,000 square feet. As with the fogging of diluted bleach, there were no visible effects to non-metallic surfaces (e.g., concrete, ballast, wood, wallboard) in the mock subway system. Some of the metal-based materials that were sprayed with PAB had slightly more oxidation and discoloration than what was observed after the fog decontamination round. These materials included items such as metal outlet boxes, unpainted areas of the stairwell handrails, metal base plates on stairs, exposed threads on galvanized steel pipe, and the Metro card fare reader. Some electrical panels and outlets were covered in plastic or tape to avoid damage. The chemical sprayer was rinsed and purged with water immediately after the decontamination event, and no immediate visible or functionality impacts were noted.

Conclusions

Several decontamination techniques found to be efficacious in inactivating *B. anthracis* spores have also been recently demonstrated in laboratory and field tests to have minimal compatibility issues with the materials they were tested with. Of the techniques discussed in this tech brief, these include MB (with no chloropicrin), LCHPV, and PAA fog. Gamma irradiation showed some impacts on all the materials tested, but this is caveated with the fact that the only materials tested were highly sensitive materials representative of items found in a museum, such as artwork, historical documents, etc. While PAB showed minimal impact to wallboard, it did present issues with spray equipment and metal-based materials. Similar to PAB, diluted bleach impacted the foggers used to disseminate it, as well as detrimentally impacting some of the metallic objects exposed to the fog. However, the selection of a decontaminant may depend on many site-specific factors, and the use of a corrosive or destructive technique may be warranted for some applications.

Disclaimer

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Contact Information

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Technical Contact: Joseph Wood (wood.joe@epa.gov)

General Feedback/Questions Contact: (CESER@epa.gov)